

THE EFFECTS OF SPACE RADIATION ON THIN FILMS OF $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$

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ABSTRACT

Thin films of polycrystalline $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ (YBCO) grown on silicon were exposed to Co-60 gamma rays and 780-keV electrons, simulating the effect of low-earth-orbit radiation. Neither a dose of 50 megarads nor a fluence of 10^{15} e/cm² produced a significant decrease in critical transition temperature.

INTRODUCTION

High temperature superconducting materials are expected to offer significant improvements in the performance of spacecraft components. Specifically, low surface resistance at high frequencies is expected to result in reduced RF losses in superconducting waveguides, bandpass filters, and antennas.

It is attractive to provide passive cooling to superconductors by locating them on the shaded side of a space vehicle, radiating directly into space. Unfortunately, the technique results in exposure to high radiation dose levels due to trapped electrons and protons in the space environment. The high energy electrons and the protons will lose most of their energy in the first few microns inside the surface. For example, a typical surface dose for a 5-year mission in low earth atmospheric remote sensing orbit is 10^{15} electron/cm² which deposits 10 Megarads (10^9 ergs/gram) of energy in surface material. This is two or three orders of magnitude higher than the dose to most satellite electronics, which are shielded by at least several millimeters of material. The effects of space radiation on superconducting properties of YBCO materials are therefore critically important in incorporating these materials into spacecraft systems. The effects of charged particle irradiation on surface morphology of superconducting thin films has been published (1-3).

This investigation had two objectives: (1) to determine the effects of space radiation on superconductor parameters that are most important in space applications and (2) to determine whether this effect can be simulated with Co-60 gamma rays, the standard test method for space materials.

EXPERIMENTAL CONDITIONS

Thin films of YBCO were formed by coevaporation of Y, BaF₂, and Cu and post-annealing in wet oxygen at 850°C for 3.5 h. The substrate used was (100) silicon with an evaporated zirconia buffer layer. Processing and microstructure studies of these types of films have been published (4-7). The zero-resistance transition temperatures of the samples used in this study were 84 to 86K. The samples were characterized by four point probe electrical measurements as a function of temperature. The parameters measured were: the zero-resistance transition temperature (T_C) and the room-temperature resistance. The samples were then exposed to Co-60 gamma rays, in air and in pure nitrogen, and to 780-keV electrons, in air. The parameters were then remeasured.

RESULTS

The results are summarized in Tables 1 and 2.

The results indicate little or no degradation in the parameters measured for samples exposed up to 50 megarads of gamma rays in nitrogen. However, complete degradation of samples exposed to 10 megarads in air was observed. This degradation is preliminarily attributed to the high level of ozone generated in the chamber by the gamma ray interaction with air. Furthermore no degradation in superconducting properties of samples exposed to 10^{15} electrons at 780 keV in air was observed.

DISCUSSION

The radiation tests show that polycrystalline YBCO films on Si are only slightly affected by gamma and electron radiation. Significant changes in the electrical properties of bulk YBCO exposed to 1-MeV electrons have been reported [8]. For these YBCO bulk materials, degradation occurred at a fluence of $6.5 \times 10^{11} \text{ e/cm}^2$. We believe that the relatively good performance of our thin films is related to the use of BaF₂ as an evaporation source.

Even though the annealing of thin films is performed in wet oxygen to remove the fluorine from the films we have found by x-ray photoelectron spectroscopy that about 1 atomic % fluorine abundance remains in the surface region. We speculate that the fluorine improves the degradation performance of these films [9]. As suggestive evidence we cite Tressaud et al, [10], who find that a thin surface layer containing fluorine provides protection against hydrolysis and gas exchange. It has also been suggested [11] that a thin surface layer containing fluorine improves the resistance of YBCO to degradation caused by thermal cycling.

CONCLUSION

It can be concluded that (1) the electron component of space radiation does not degrade the critical temperature of the YBCO films described herein, at least for energies around 800 KeV and doses similar to those received by surface materials on spacecraft in typical remote sensing missions; (2) for qualifying this and other superconducting materials against the space-radiation threat the standard test method used in the aerospace industry, namely, exposure to Co-60 gamma rays in air, may require some further investigation. As a minimum, the sample must be either in vacuum or in positive nitrogen pressure.

The results of this study and that reported in [11] are encouraging for the use of YBCO films in low earth orbit satellites because these films resist degradation from radiation [this paper] and temperature cycling [11]. Thus, even with a lack of protective layers, passive cooling can be provided to the thin YBCO films by exposing them to space without concern about radiation damage.

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SAMPLE DESCRIPTION	AMBIENT ENVIRONMENT	GAMMA-RAY DOSE (Mrad)	TRANSITION TEMPERATURE (K) BEFORE AFTER		COMMENTS
			EXPOSURE	EXPOSURE	
1a) YBCO on Si	Air	10	86	--	Catastrophic failure
1b) YBCO on Si	Air	100	85	--	Complete erosion of superconducting film
2a) YBCO on Si	Nitrogen	10	85	84	No degradation in Tc
YBCO on Si	Nitrogen	50	85	84	No degradation in Tc
2b) YBCO on Si	Nitrogen	10	86	82	Slight degradation in Tc
with silver pads	Nitrogen	50	86	81	
3) YBCO on Si	Air	--	85	85	No degradation in Tc
(Control Sample) *					(after 21 days)

*The control sample was placed outside of the Co-60 source and its superconducting properties were compared to the exposed samples.

TABLE 1: SUMMARY OF GAMMA-RAY EXPOSURES ON SUPERCONDUCTING MATERIALS

SAMPLE DESCRIPTION	AMBIENT ENVIRONMENT	ELECTRON DOSE	TRANSITION TEMPERATURE (K) BEFORE AFTER EXPOSURE EXPOSURE	COMMENTS
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1) YBCO on Si	Air	10 ¹⁵ electron/cm ²	84 84	No degradation in T _c
2) YBCO on Si (Control Sample)*	Air	---	85 85	No degradation in T _c

* The control sample was placed outside of the electron generator and its superconducting properties were compared to the exposed samples.

TABLE 2: SUMMARY OF ELECTRON EXPOSURES ON SUPERCONDUCTING MATERIALS